UNCLASSIFIED

CONFIDENTIAL

Copy 6
RM L9D18

NACA RM L9D18

~~5344~~
~~513~~
2

NACA

RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF 3-INCH SLOTTED TRANSONIC WIND-TUNNEL TEST SECTIONS

By George P. Bates

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

CLASSIFICATION CANCELLED

Authority J. W. Crowley Date 3/10/54

By MN2HA 3/30/54 See NACA

R.A. 2303

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
September 9, 1949

UNCLASSIFIED

CONFIDENTIAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF 3-INCH SLOTTED TRANSONIC WIND-TUNNEL TEST SECTIONS

By George P. Bates

SUMMARY

Preliminary investigations have been made of two 3-inch-diameter slotted test sections over a range of pressure ratios from 1.3 to 10.0. One of the test sections had 20 slots with $\frac{1}{5}$-open wall area, while the other had 8 slots and was 1/8 open.

The two test sections showed no appreciable difference in performance. The Mach number could be varied continuously from low subsonic values to supersonic values of about 1.7 with the pressure ratios available. The distribution of Mach number along the axis of the test section was reasonably uniform at Mach numbers up to about 1.2. Beyond this speed the pressure gradients became so large that the flow could not be used for test purposes.

INTRODUCTION

As a preliminary part of the comprehensive investigation of slotted test sections that is being carried out by the National Advisory Committee for Aeronautics, the flow has been investigated in two test sections of 3-inch diameter. The stagnation pressure has been varied from 20 pounds per square inch to 150 pounds per square inch.

Previous research at the Langley Aeronautical Laboratory (reference 1) has indicated that tunnel-wall interference at high subsonic and transonic Mach numbers can be alleviated by the use of a slotted test section. The present investigation of slotted test sections was made over a more extensive range of pressure ratio, 1.3 to 10.0, than the ratios of 1.2 to 2.4 reported in reference 1 in order to determine whether the flow could be expanded to higher supersonic Mach numbers with uniform velocity distribution. Investigations were made with and without a chamber surrounding the test sections. In both configurations, data were taken with the effuser at the downstream end of the test section installed inside the slots and also with the effuser located entirely outside the slots.

SYMBOLS

A_{min}	minimum cross section of area of tunnel at entrance cone
A_1	cross-sectional area of tunnel at effuser, not including area inside slots
A_2	cross-sectional area of tunnel at effuser, including open area inside slots
a	velocity of sound in air
D	diameter of tunnel throat (3 in.)
H	stagnation pressure in settling chamber
M	stream Mach number (V/a)
p	local static pressure
h_1	measured stagnation pressure in test section corrected for loss through a normal shock at stream velocity
S	station measured from midpoint of test section along tunnel longitudinal axis
V	stream velocity

APPARATUS AND METHODS

The general arrangement of the test setup is shown in figure 1. The settling chamber was 12 inches in diameter and 36 inches long and was faired to a 3-inch minimum diameter just upstream from the test section. This entrance cone was designed to give a uniform acceleration up to a Mach number of unity at the minimum section. The test section was 14 inches long, with an included divergence angle of 0.4° to allow for boundary-layer increase as encountered in a closed-throat tunnel. A 10-inch length of the test section was slotted. At the end of the test section the jet expanded abruptly without any fairing into a 5-inch-diameter tube (diffuser pipe) that was 48 inches long. A valve was placed at the end of the pipe so that the pressure ratio across the test section could be held constant for various stagnation pressures.

A diagrammatic sketch of the test section, enclosed in the chamber, is shown as figure 2. The two separate test sections that were used were of the same general dimensions and shape but differed in slot width and number of slots. In both sections the slots were 10 inches long and 1 inch deep. The bars that formed the walls of both test sections had parallel sides, so that the slot width increased as the distance from the jet axis increased. One section was a duodecagon with slots located at the corners and had approximately one-fifth of the test-section perimeter open (fig. 3). The upstream end was faired into the 3-inch-diameter section of the entrance cone. The bars for this test section were so constructed that thin baffles could be located in planes normal to the tunnel axis within the slots at $\frac{1}{2}$-inch intervals along the length of the slots, with the innermost edge of the baffle approximately 1/4 inch from the test-section perimeter. The other test section was of circular cross section and had 8 slots with a total of approximately one-eighth of the periphery open. The section was constructed of bars 1 inch thick placed in a 3-inch circle (fig. 4).

The entrance lip (fig. 2) and the effuser bells inside and outside the slots (figs. 3 and 4) were the same for both test sections. The entrance cone was terminated in a sharp lip inside the slots to minimize the formation of vortices at the leading edge of the slots. The effusers within the slots were circular arcs of $\frac{1}{2}$-inch radius and were placed in the slots so that they were flush with the inside surface of the test section (fig. 3(b)). Tests were also made without an effuser in the slots and with an effuser of $2\frac{1}{2}$-inch radius placed outside of the slots (fig. 4(b)). For each of the latter configurations the minimum effuser area A_2 was nearly 54 percent larger than the original effuser area A_1. The area A_2 was less than the value calculated from the $5\frac{3}{32}$-inch-diameter hole in the downstream bar-retaining ring (fig. 4(a)) because of the welding bead in the slots.

The chamber that was placed around the test sections had a 17-inch-square cross section, almost six test-section diameters. This chamber was considerably larger than would normally have been installed but the size was required to fit with existing equipment. The chamber was equipped with a valve vented to atmospheric air so that some regulation of the chamber pressure could be achieved.

The stagnation pressure H of the air stream was measured by a blunt total-pressure tube placed in the settling chamber. Local static pressure on the wall of the test section was determined from orifices placed in the center of one of the bars that made up the test-section wall (fig. 2). A long static tube of $\frac{1}{8}$-inch diameter was used to obtain the static pressure at five points along the jet center line. Total-pressure surveys were made at several locations in the test section with the use of seven flat-end tubes of 0.050-inch diameter as the rake tubes. The flat ends of the tubes were 1 inch ahead of the support body, a 10-percent circular-arc section of 1-inch chord having a frontal area of 0.3 square inch.

Pressures were recorded photographically from a mercury-filled, multiple-tube manometer. The Mach numbers in the test section were determined from local static pressures in the test section, assuming no loss in total pressure from settling chamber to test section.

A miniature inductive-type pressure pickup gage designed and constructed at the Langley Laboratory was installed in the test-chamber wall to determine the amplitude and frequency of the pressure pulsations within the chamber.

The equipment for these preliminary slotted-throat tests was hastily assembled; however, the results are believed indicative of the flow changes that would occur at high pressure ratios.

RESULTS AND DISCUSSION

No chamber around the test section.- Various tests were made to determine the operational characteristics of the slotted test sections with the slots open to atmospheric conditions. In general, there were no large differences between the characteristics of the 8-slot test section and the 20-slot test section.

Figure 5 is a comparison of the static-pressure distribution along the center lines of the 8-slot and the 20-slot test sections with the effusers inside the slots. The stagnation pressure for the 8-slot test section was slightly less than that for the 20-slot section; at Mach numbers below 1.1 this difference accounts for a large part of the displacement of the two curves.

Figure 6 shows the typical static-pressure distribution along the wall and center line of the 20-slot test section for the configuration in figure 5. The acceleration of the flow inside the solid nozzle to speeds slightly above $M = 1$ when the test section is at supersonic speeds is probably due to a change in boundary-layer thickness near the entrance lip of the slotted-throat section. At and below stream Mach numbers of 1.1 the axial velocity distribution along the wall showed a change in Mach number of not more than 0.025 for a distance of slightly over one test-section diameter upstream and downstream from the center of the test section. The axial variations in Mach number along the center line were somewhat less than the variations at the walls at stream Mach numbers of 1.1 or less. The differences between the static pressure on the wall and in the center of the jet at a given axial location in the test section corresponded to a change in Mach number of as much as 0.03. At Mach numbers from 1.1 to 1.7 the axial variations at both wall and center line and the cross-stream static-pressure variations increased with an increase in stream Mach number.

Total-pressure surveys across the stream in the test section showed quite uniform pressure distributions at all flows. The total-pressure rake was located as shown in figures 3(a) and 4(a). Figure 7 indicates that at a station 8 inches down from the entrance lip of the test section, the total-pressure loss $1 - \frac{h_1}{H}$ near the axis is less than 0.01 at a Mach number of 1.11. For this condition the mixing region is approximately 3/4 inch thick. At higher speeds the total-pressure losses become greater and the thickness of the mixing region inside the slotted test section decreases. The decrease in thickness of the mixing region with increase in stream Mach number probably results from the increased expansion of the flow out into the slots at higher stagnation pressures.

The data obtained with screens placed around the outside of the 1-inch-deep slots (not included herein) showed that the major flow changes occurred within the slots. Baffles which extended to within 1/4 inch of the inside wall of the test section were placed in precut grooves in the wall bars so as to affect control of longitudinal flow within the slots, but the baffles created disturbances of varying intensity in the slots without causing any noticeable changes in the pressures distribution along the wall. (Compare fig. 8 with fig. 6.) It must be noted, however, that the static-pressure orifices were identically located with respect to the baffles and might therefore fail to indicate the actual pressure distribution. A sketch showing the location of the static-pressure wall orifices in relation to the baffles is included at the top of figure 8. In an effort to force the air to flow out through the slots the exit air pressure was increased by constricting the flow at the valve in the diffuser pipe (fig. 1). The increase in back pressure forced a normal shock upstream into the test section. While more flow was forced out through the slots downstream of the shock, the flow upstream of the shock was unaffected.

Slight decreases in positive pressure gradients at the end of the test section were affected by increasing the effuser area, but the pressure variations at other stations in the test section were not appreciably changed. The ineffectiveness of an effuser bell outside the slots (fig. 4) provided additional substantiation of the conclusion that the the major flow changes occurred within the 1-inch-deep slots.

Closed chamber around test section.- A square chamber of approximately six test-section diameters was placed around the test section to permit regulation of the static pressure outside of the slots.

Tests made on the 20-slot test section, with the original $\frac{1}{2}$-inch-radius effuser inside the slots, indicated that the test section was choked at the point of minimum effuser area. Results of tests of the

8-slot section (one-eighth of periphery open), with the $\frac{1}{2}$-inch-radius effuser inside the slots, showed that it was impossible to exceed a stream Mach number of 0.85 at the test section, regardless of the pressure ratio applied. While the velocity distribution along the axis and across the stream was fairly good, all the data indicated that the flow through the test section when enclosed within a sealed chamber was completely choked at the effuser minimum.

Since the flow was constricted, the effuser bells inside the slots were removed from both of the test sections and tests were conducted with the slots clear. The 20-slot test section with the large effuser was not choked at any pressure ratio tested, and a pressure ratio of 3 (45 psi absolute in the settling chamber) was sufficient to give a test section Mach number of 1.7. Increasing the pressure ratio above 3 had little effect on the flow in either test section. Although no tests were made with a diffuser of improved design, it seemed probable that a correctly designed diffuser at the end of the test section would reduce the pressure ratio required to operate this apparatus with a chamber.

Figure 9 gives the axial velocity distribution in the 20-slot section with an effuser bell outside the slots for various stagnation pressures. The axial variations in Mach number on the wall of the test section over a length of two test-section diameters were 0.02 at $M = 0.9$, 0.03 at $M = 1.1$, and 0.06 at $M = 1.2$. Above a Mach number of 1.2 the variations increased more rapidly with the Mach number. The axial velocity variations along the center line of the jet were larger than those on the wall, being of the order of 0.1 at $M = 1.1$ and becoming much larger at higher speeds. The change in Mach number across the stream from wall to center line was 0.06 at Mach numbers between 1.1 and 1.2 but increased at higher speeds. Although no attempt has been made to arrive at an optimum configuration, it is entirely possible that variations in slot profile, external pressure along the slots, and effuser shape would produce much smoother flow than that shown.

The chamber static pressure was less than atmospheric pressure for all stagnation pressures below 50 pounds per square inch, so it was possible to increase the static pressure in the chamber by allowing air to flow from the atmosphere into the chamber through a valve placed in the chamber wall. Increasing the chamber pressure caused an almost uniform drop in Mach number both at the wall and along the center line, but the existing absolute variations were not affected. Similar results were obtained with the 8-slot test section. The main apparent effect of the chamber was to reduce the stagnation pressure required to operate the tunnel by reducing the static pressure in the test section.

A total-head rake with a frontal area of 0.3 square inches placed across the 8-slot test section 5 inches downstream of the entrance lip indicated that the mixing region extended only about 1/4 inch from the wall. The decrease in thickness from the $\frac{3}{4}$-inch mixing region encountered 8 inches downstream of the lip may be due to the fact that the increased area at the effuser allowed the air to expand out into the slots more than before, or to the fact that the other tests were made in the 20-slot section with only one-fifth of the perimeter open.

At supersonic speeds the total-pressure survey rake caused a large disturbance on the wall, as is shown by the bump on the wall velocity-distribution curve of figure 10, at and behind the rake. The disturbance was present in both test sections but was less pronounced in the 20-slot section, probably because the 20-slot section had more open area than did the 8-slot section. The one-dimensional choking Mach number for a body the size of the rake when placed in a closed wind tunnel is 0.785, but in the slotted test section the Mach number could be increased to supersonic values.

The frequency and the amplitude of the pressure pulsations in the chamber were measured by an NACA miniature inductive pressure gage. The frequency of the pulsations in the chamber for the 8-slot and 20-slot sections, with the downstream ends of the slots open, was about 2000 cycles per second at and above $M = 1.3$ but was only about 900 cycles per second at $M = 0.9$. The amplitude of the pulsations for the 8-slot section at velocities above $M = 1.35$ was of the order of 2 percent of the chamber static pressure but increased to a peak at a Mach number of 1.27. Below 1.27 the amplitude again decreased. The 20-slot section followed the same trends but had much higher amplitudes until a test section Mach number of 1.55 was reached. At low speeds the sound of the tunnel was a low rumble, but at the higher speeds the sound level was around the threshold of feeling.

CONCLUSIONS

From the results of these preliminary tests made on two slotted-throat test sections of 3-inch diameter, it is concluded that:

1. The flow in a fixed-geometry slotted test section can be expanded through the transonic range to a Mach number of 1.7 by increasing the pressure ratio.

2. Above the stream Mach number of 1.2 large gradients in the velocity through the slotted test section reduced the usefulness as a wind tunnel to limited applications.

3. Slight changes in the test-section velocity distribution were the primary effects of the change from an 8-slot test section with $\frac{1}{8}$-open perimeter to a test section with 20 slots and $\frac{1}{5}$-open perimeter.

4. The main effect of placing a sealed chamber around the test section was to decrease the pressure ratio required to operate the apparatus. The chamber produced only small changes in the test-section velocity distribution.

5. Placing a sealed chamber around a slotted test section requires that an effuser area somewhat larger than the test-section area be used in order to prevent choking at the effuser minimum.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

REFERENCE

1. Wright, Ray H., and Ward, Vernon G.: NACA Transonic Wind-Tunnel Test-Sections. NACA RM No. L8J06, 1948.

[redacted]

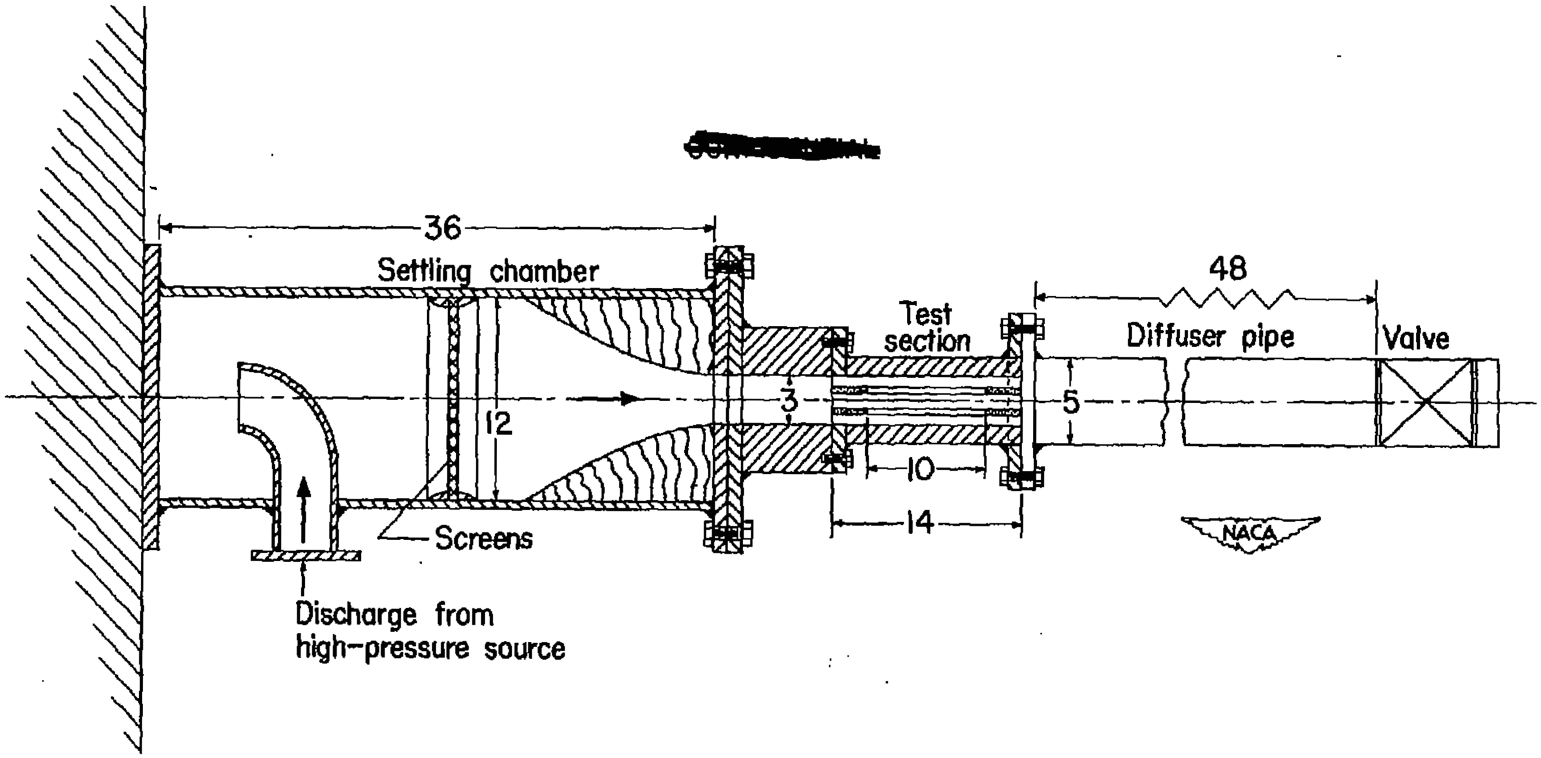


Figure 1.- Section view of 3-inch slotted-throat jet. All dimensions are in inches.

[redacted]

[redacted]

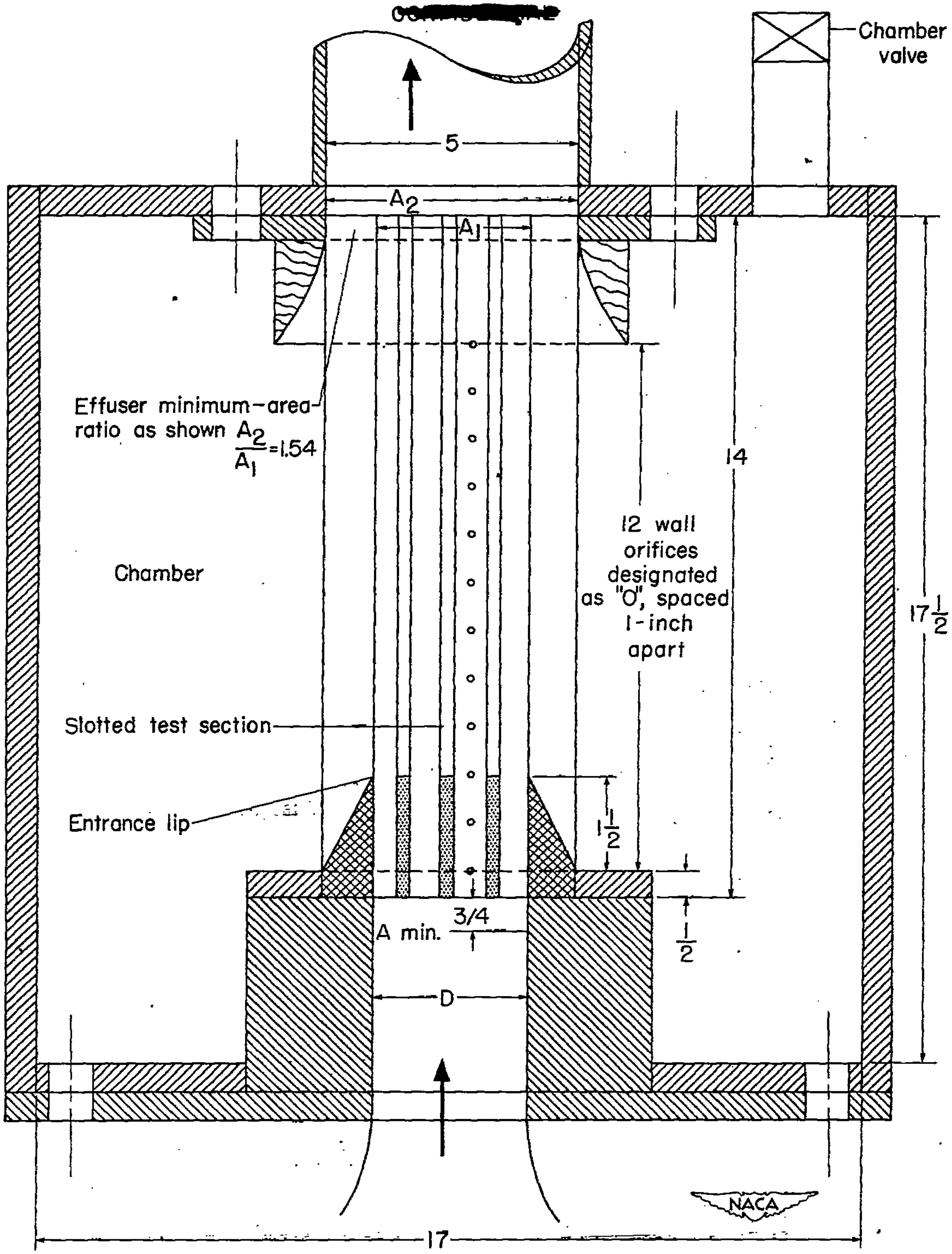
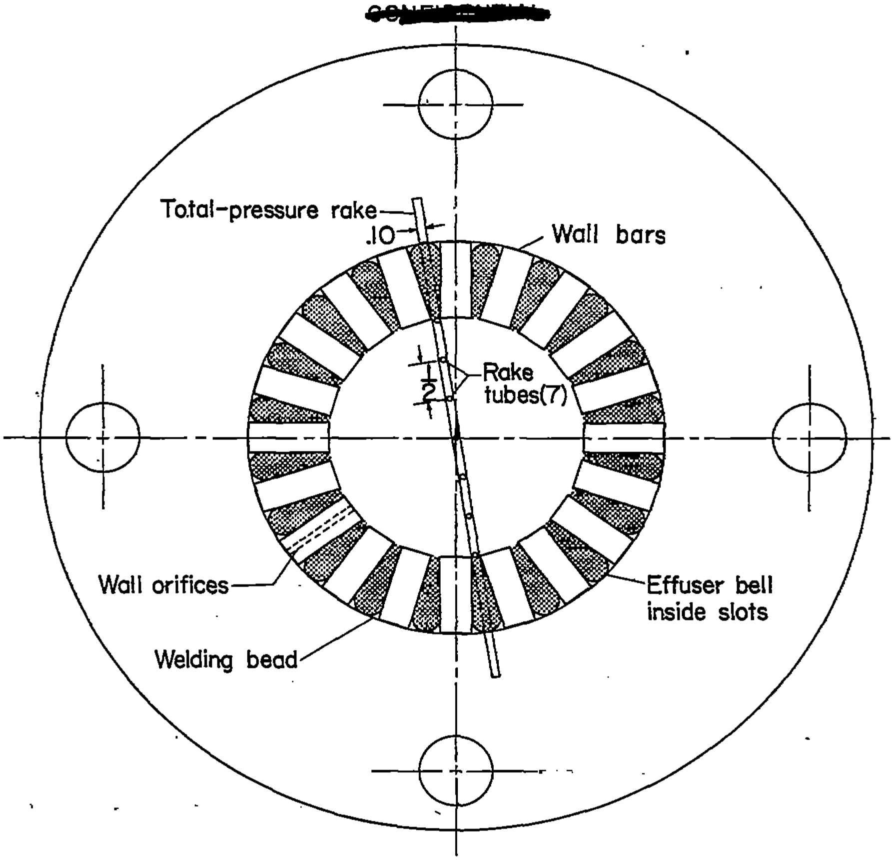


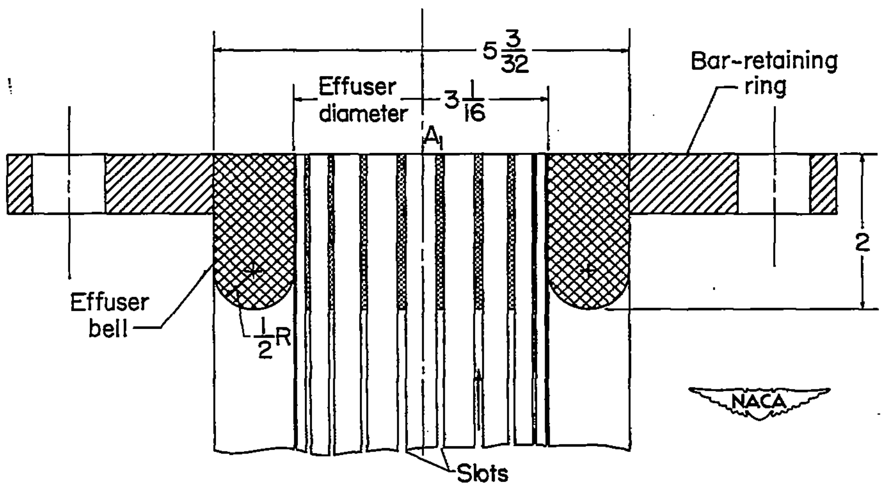
Figure 2.- Slotted-throat test section enclosed in chamber. All dimensions are in inches.

[redacted]

[redacted]



(a) Top view of test section.

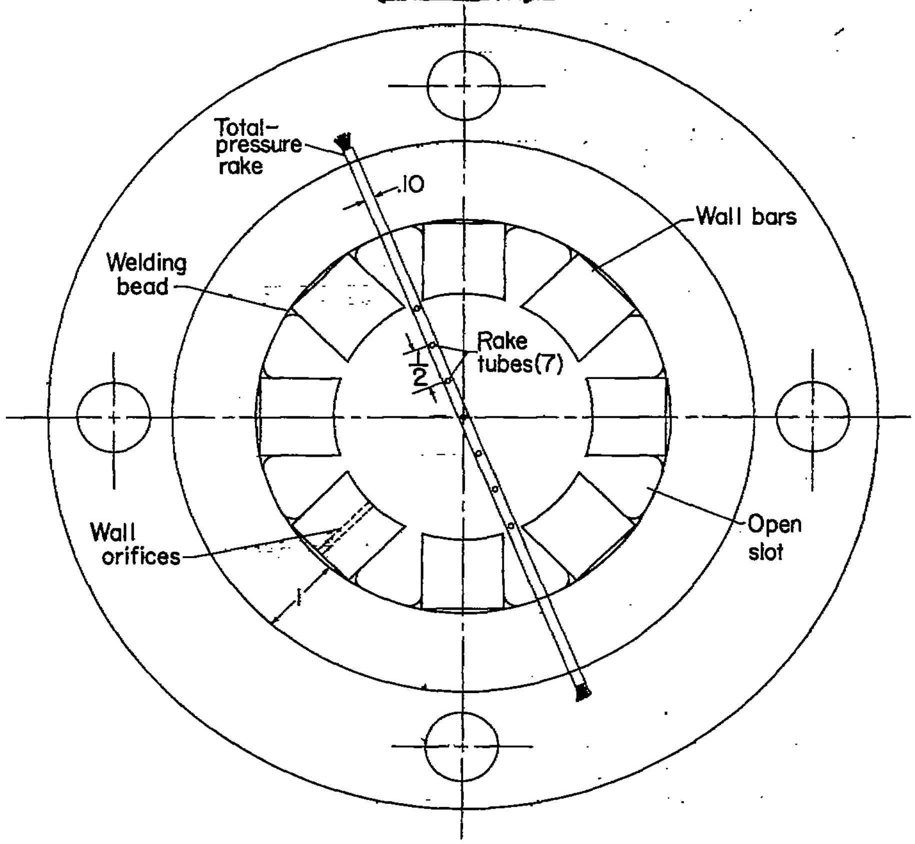


(b) Section view of downstream end of test section showing effuser shape and location.

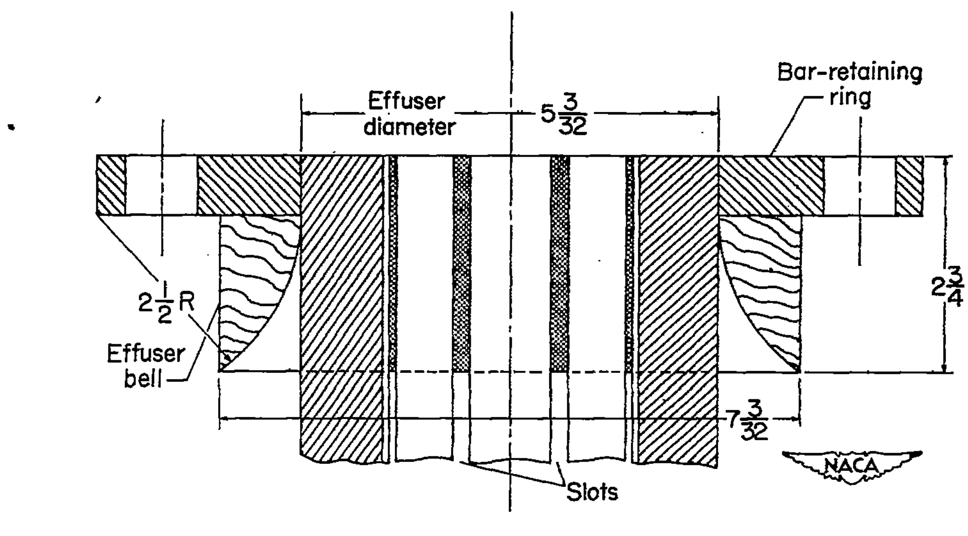
Figure 3.– Twenty–slot test section with effuser bell inside slots.

[redacted]

[redacted]



(a) Top view of test section.



(b) Section view of downstream end of test section showing effuser shape and location.

Figure 4.– Eight-slot test section with effuser bell outside slots.

[redacted]

[redacted]

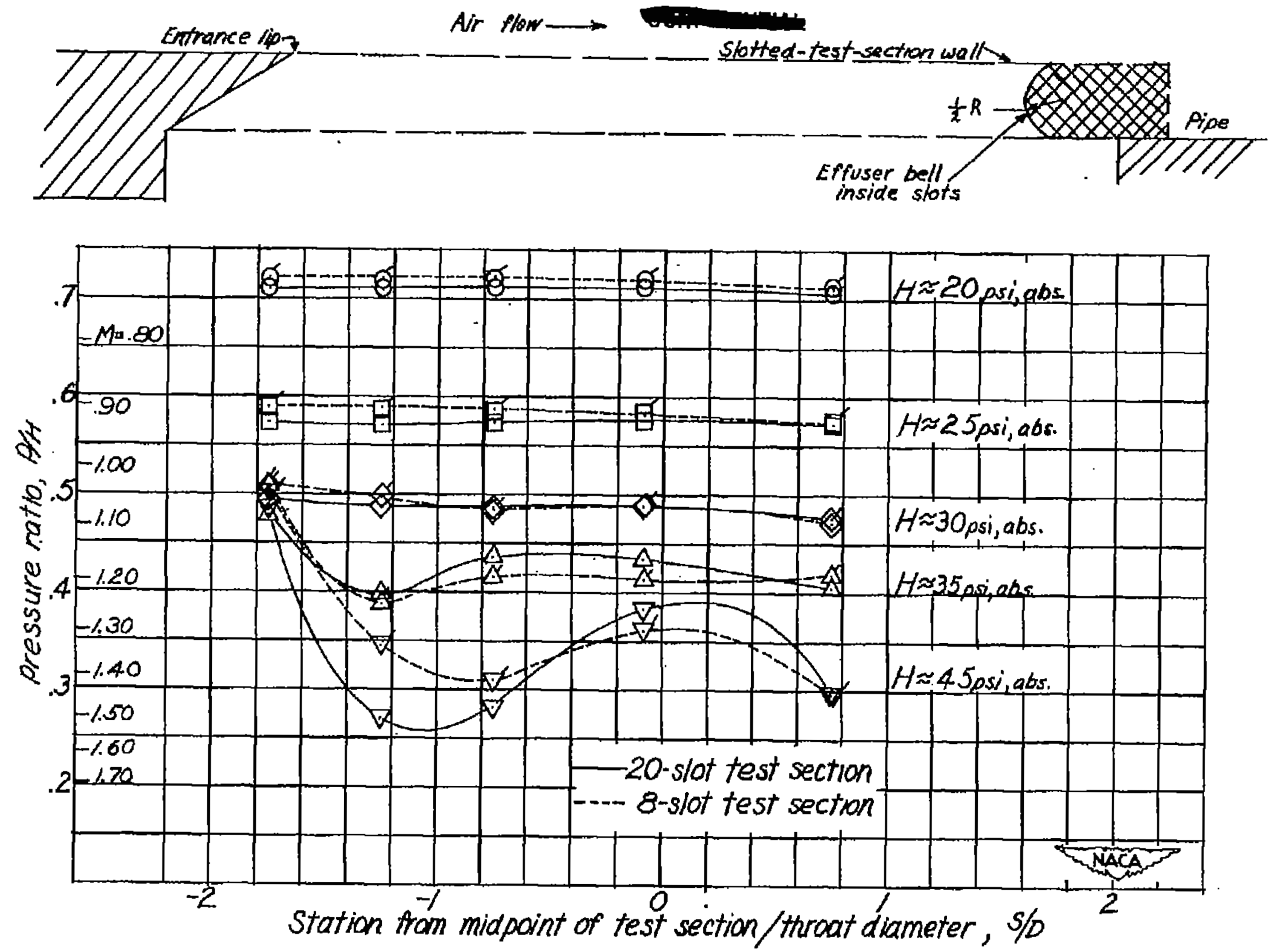


Figure 5.— Comparison of axial static-pressure distribution along the center lines of the 8-slot and 20-slot test sections. Sections not enclosed in chamber.

[redacted]

[redacted]

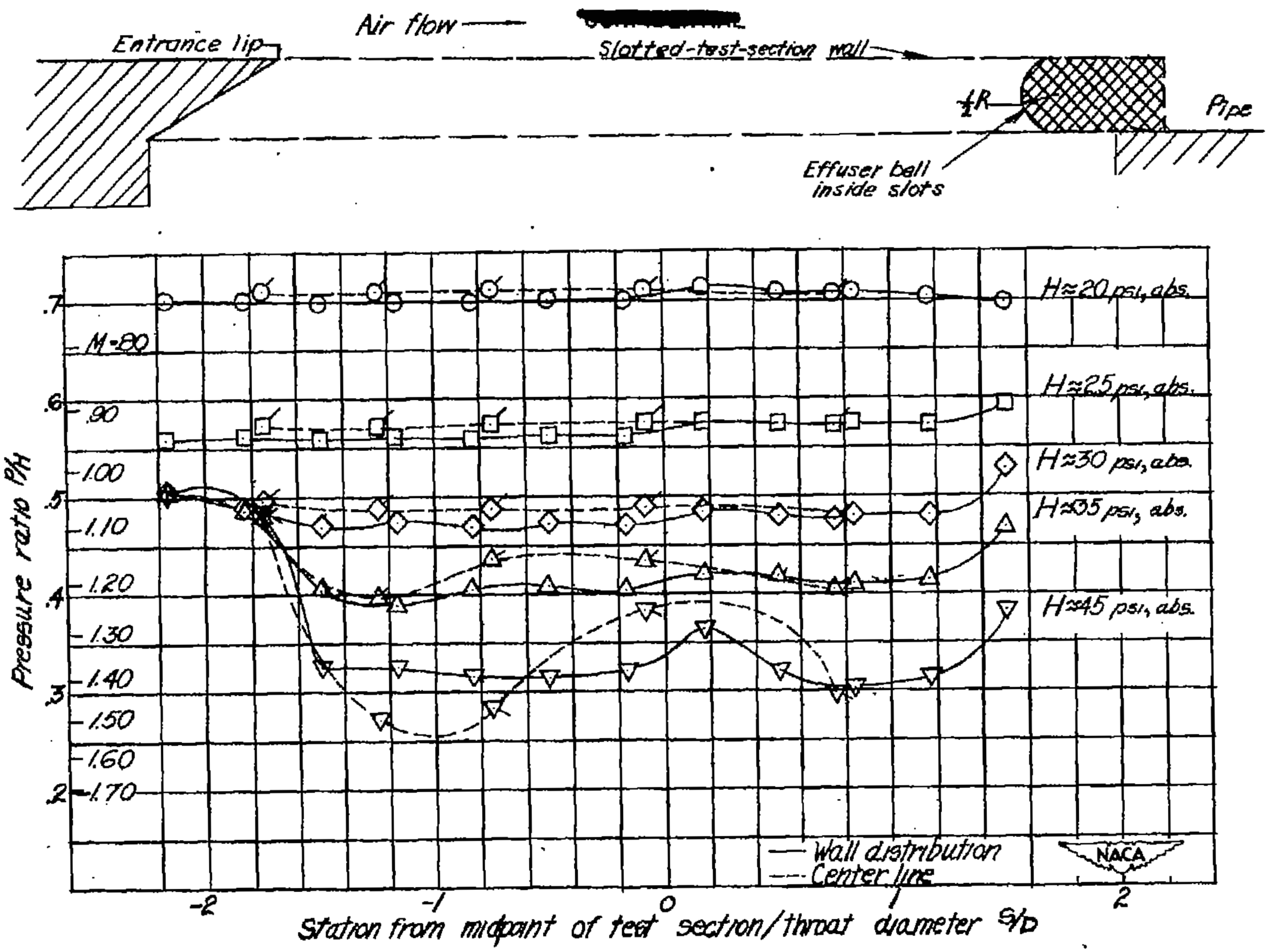


Figure 6.- Axial pressure distribution along the wall and center line of the 20-slot test section. Section not enclosed in chamber.

[redacted]

[redacted]

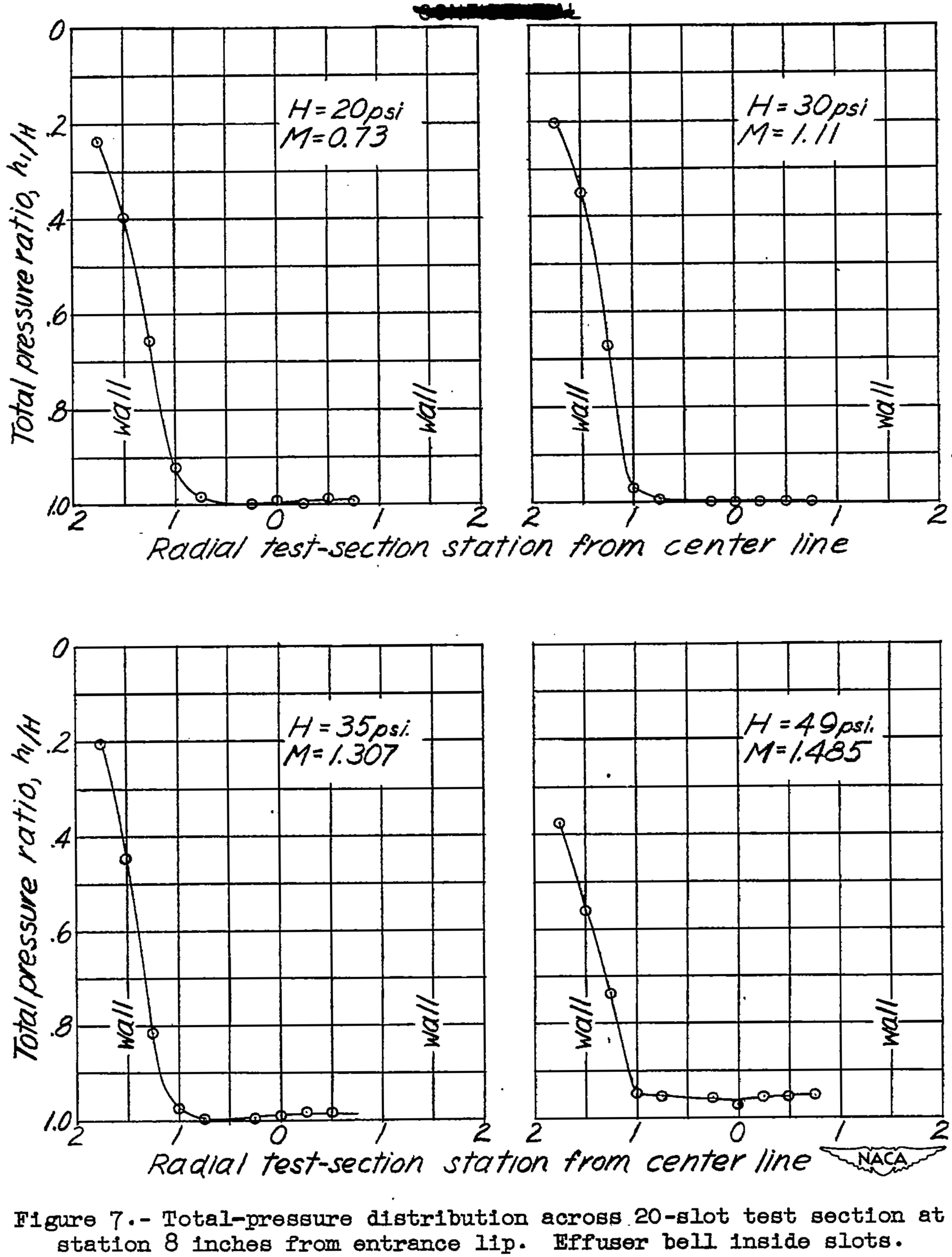


Figure 7.- Total-pressure distribution across 20-slot test section at station 8 inches from entrance lip. Effuser bell inside slots. Section not enclosed in chamber.

[redacted]

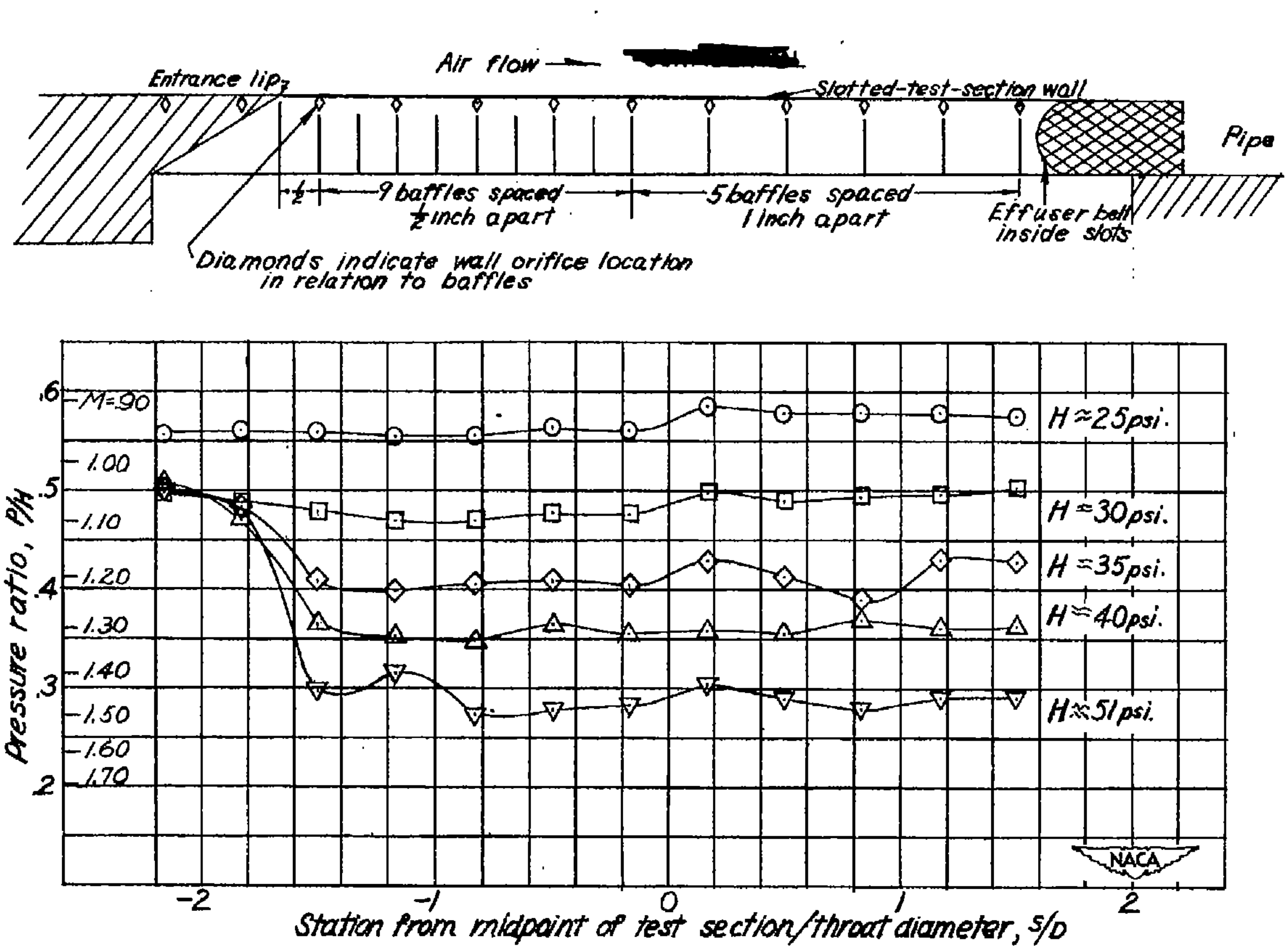


Figure 8.– Axial pressure distribution along wall of 20-slot test section with baffles placed in slots. Section not enclosed in chamber.

[redacted]

[redacted]

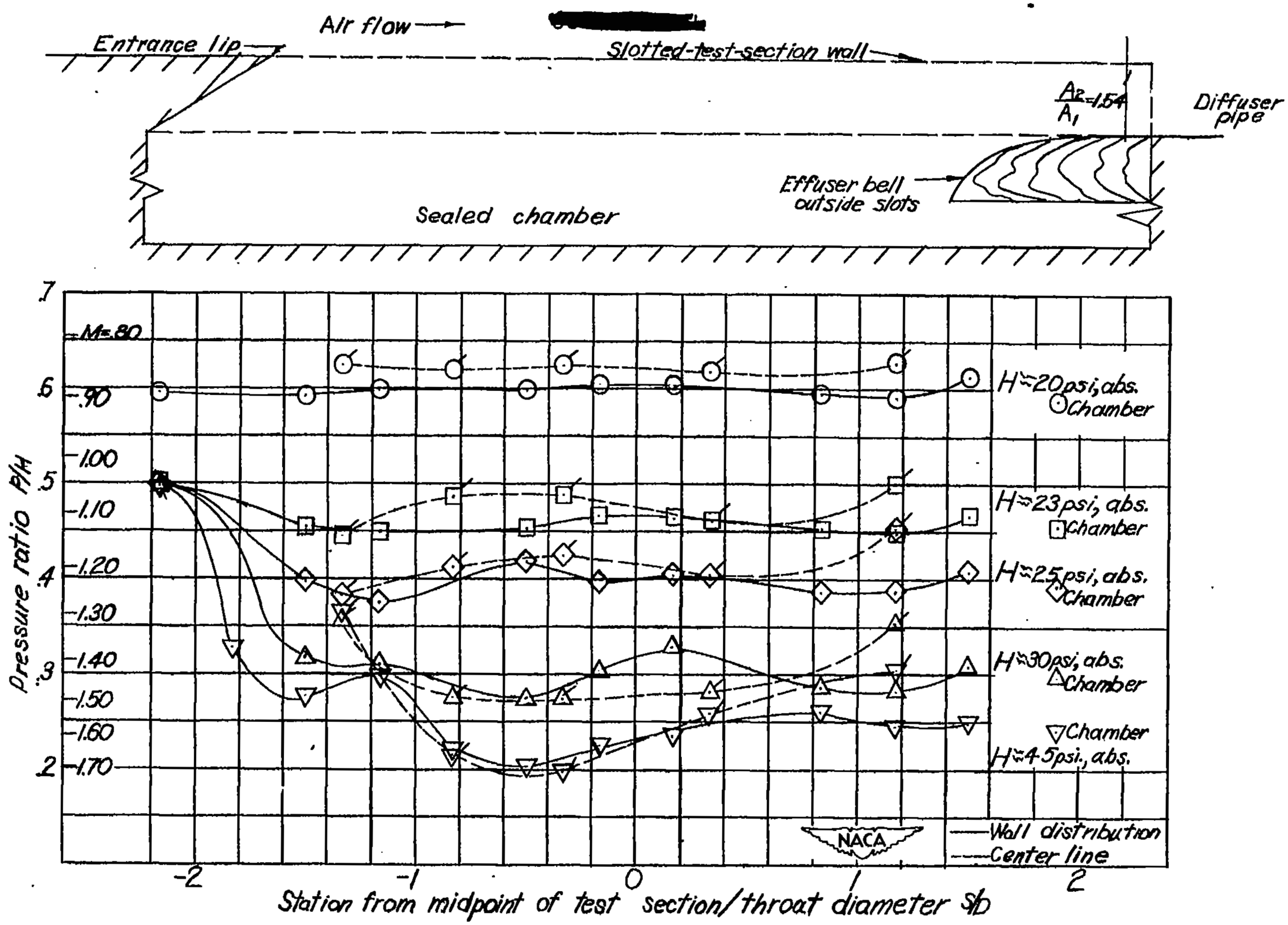


Figure 9.– Axial pressure distribution along the wall and center line of the slotted test section enclosed in chamber.

[redacted]

[redacted]

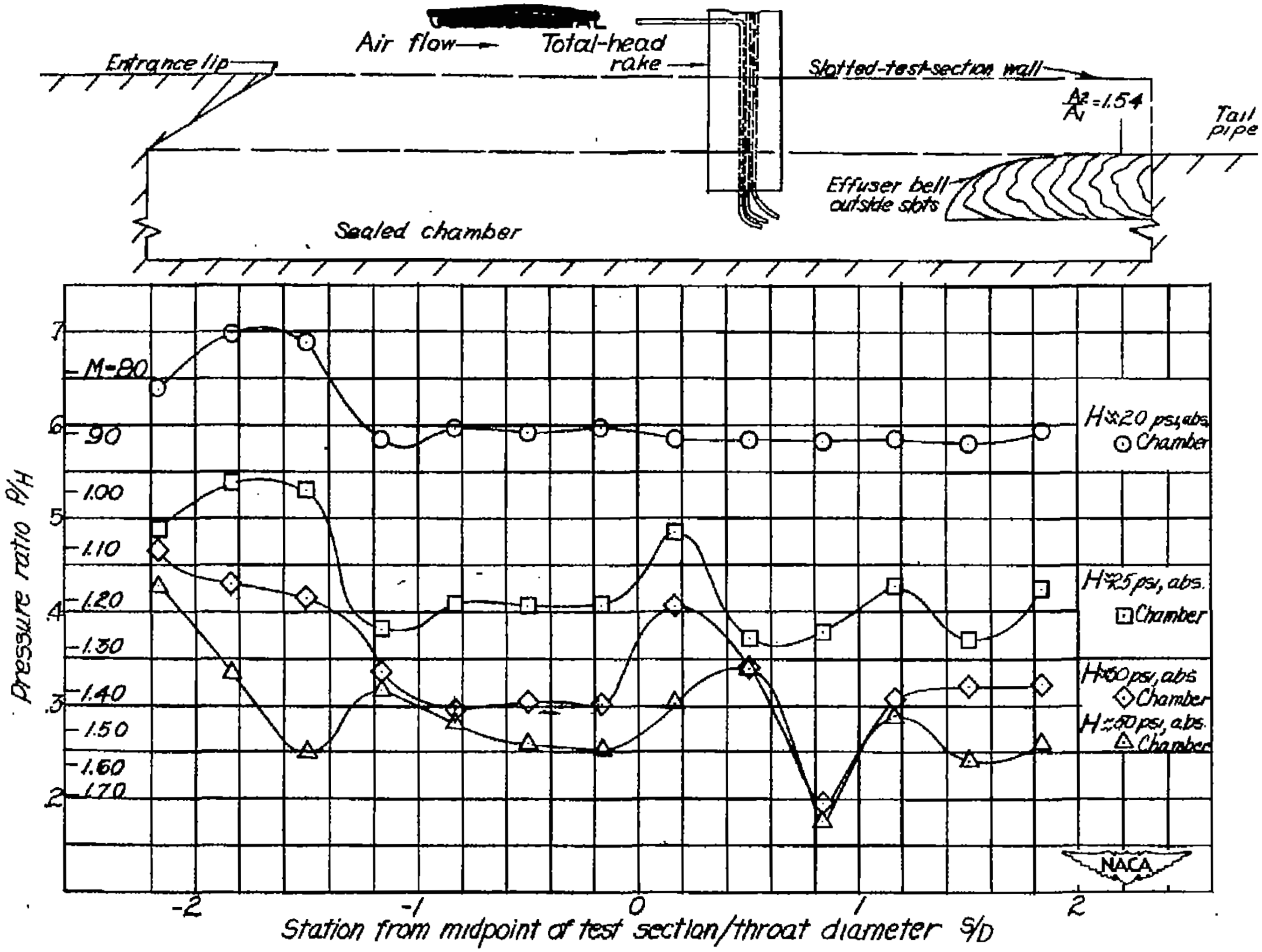


Figure 10.– Axial pressure distribution along the wall of the slotted test section. Section enclosed in chamber. Total–head rake spanning the test section.

[redacted]

NACA-Langley - 9-8-49 - 300